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ANALYTICAL MODEL OF SPIT EVOLUTION AT INLETS

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Abstract: The evolution of spits at inlets located on alluvial shores is examined from the perspective of process-based modeling. Hydrodynamic and morphologic processes controlling spit evolution are first identified and classified according to major spit parameter and time scale. An analytical model of spit evolution is then presented that describes cause and effect between selected spit parameters and the acting processes, focusing on spit elongation and its rate of change. Predictions and trends from the model are examined by reference to measurements of spit growth in Corpus Christi Bay, Texas, and to spits generated in a movable-bed physical model. It is concluded that considerable progress can be made in quantifying spit dynamics at inlets.

INTRODUCTION

Spits are organized surface-piercing accumulations of sediment that grow by transport directed from a landmass or sediment source toward a water body. Spits can form at the ocean and bay sides of inlets and are of interest both for understanding inlet morphodynamics and for managing navigation channels and inlets. Inlet closure through spit development has implications for water quality, as well as for commercial and recreational navigation. Submerged shoals that grow from larger landmasses, such as shoals that form around the ends of jetties or the bypass bars that extend toward the shore from ebb-tidal shoals, can be considered subaqueous spits governed by similar processes.

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14. ABSTRACT
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Aubrey and Gaines (1982) describe three mechanisms by which spits are created and grow. In the present paper, discussion is restricted to the commonly observed mechanism of spit elongation by down-drift accumulation of sand introduced by longshore transport. Kumar and Sanders (1974) summarize the nomenclature and early work on spit processes (see also, Schwartz 1972), including a case study of the famous spit (Democrat Point) at Fire Island Inlet on the south shore Long Island, New York. Based on maps and surveys compiled by the U.S. Army Corps of Engineers (Gofseyeff 1953), Kumar and Sanders found that Democrat Point and Fire Island Inlet had moved westward (toward New York City) at an average rate of 63.6 m/year for the period 1834-1955, with the range varying between 5.4 and 251.4 m/year. Many geomorphologic and engineering studies have investigated spit growth (e.g., Schwartz 1972, Jimenéz et al. 1997; Orford et al. 1996; Tanaka et al. 1995; Uda and Yamamoto 1991). Moore and Cole (1960) appear to be the first to relate measured volume change of an elongating spit to wave-induced longshore sediment transport.

Inlet spit dynamics have received little attention, yet as an organized motion the possibility exists for developing tractable quantitative models describing spit evolution. This paper presents such an analytical approach through a process-based model for predicting spit elongation and deformation under simplified conditions. The model can be extended to describe complex physical situations, both analytically and numerically. The model is process-based in calculating evolution through time-averaged quantities representing meso- to macro-scale motion over intervals on the order of hours to days and over tens to hundreds of meters alongshore. Model predictions are examined by reference to the behavior of a spit along Corpus Christi Bay, Texas, and to spits generated in a laboratory study performed as part of the Coastal Inlets Research Program of the U.S. Army Corps of Engineers.

CLASSIFICATION OF PROCESSES GOVERNING SPIT EVOLUTION

The model described below derives from observations of spit evolution and quantification of morphological change based on modern understanding of the acting coastal processes. For example, spits in particular bodies of water (for example, lakes, lagoons, bays, and ocean) or along the same coast are expected to have the same characteristic width, elevation above mean sea level, and elongation speed. Table 1 presents a classification of spit macro-properties and processes by time scale.

Several dependencies listed in Table 1 emerge in development of the analytical model. Some authors have emphasized the influence of wave height on spit width and elevation. Elevation of a berm depends primarily on wave uprush or runup. By Hunt's formula, runup depends linearly on wave period and only as the square root of wave height. Therefore, wave period enters prominently in creating spit "thickness" – its width and elevation. Greater tidal range carries the runup to greater elevation, increasing spit elevation.

Temporal variability in forcing includes weather cycles on scales from days to global weather patterns over decades, such as El Niño events, and intermittence in sediment supply as from river discharges and variations in direction of longshore transport. Intermittence in sediment supply as from reversal in transport may have direct bearing on spit recurving. However, as a first step, the present work primarily treats constant forcing through time.

Table 1. Parameters controlling inlet spit geometry and evolution, and the associated processes

Spit Parameter	Short Term	Long Term[1]
Length	Longshore transport rate; proximity to inlet channel; strength of channel current	Sediment supply; geologic controls; breaching (bayward or seaward); cyclic & intermittent forcing
Elongation speed	Longshore transport rate; grain size; proximity to inlet channel; beach slope and depth-contour gradients parallel to spit	Cyclic and intermittent forcing[2]
Width	Run-up elevation; tidal range; depth-contour gradients perpendicular to spit	(see Overwash fans below)
Overwash fans	Storm surge; frequency of storms	Dunes and other blocking features; depth of receiving bay or lagoon
Elevation above MSL	Run up; tidal range	Aeolian transport; relative sea-level change; tsunami
Depth of closure	Wave height and period; tidal range; grain size	Extreme storms; elapsed time
Tendency to recurve	Proximity to channel; channel current; wave focussing; extreme storms	Cyclic and intermittent forcing

1. Long-term processes encompass those of short-term processes in same category.
2. Cyclic and intermittent forcing arises from seasonal and annual changes in wind and waves, arrival of storms and weather fronts, annual and inter-annual change in water level, etc.

ANALYTICAL MODEL

In developing the analytical model of spit evolution, standard assumptions entering shoreline-change mathematical modeling are applied (e.g., Hanson and Kraus 1989; Larson et al. 1997). In particular, we assume (see Fig. 1 for notation):

- The spit elongates solely by gradients in longshore sediment transport rate Q;
- The spit maintains a constant width, W;
- Active movement of the spit occurs within the vertical distance D composed of the sum of the berm elevation B and depth of closure D_C measured from a common datum such as mean water level; and
- Contours of the spit move in parallel over representative time scales.

Based on a laboratory physical-model study and interpretation of field evidence, Meistrell (1972) introduced the concept of "spit-platform," comprised of a spit or ridge above mean low water level that resides on the platform – a sedimentary structure elevated above the ambient shelf, but below mean low water. Meistrell found that growth of the platform preceded formation of the spit. Here, the term "spit" will represent both the subaerial ridge and platform, unless otherwise stated.

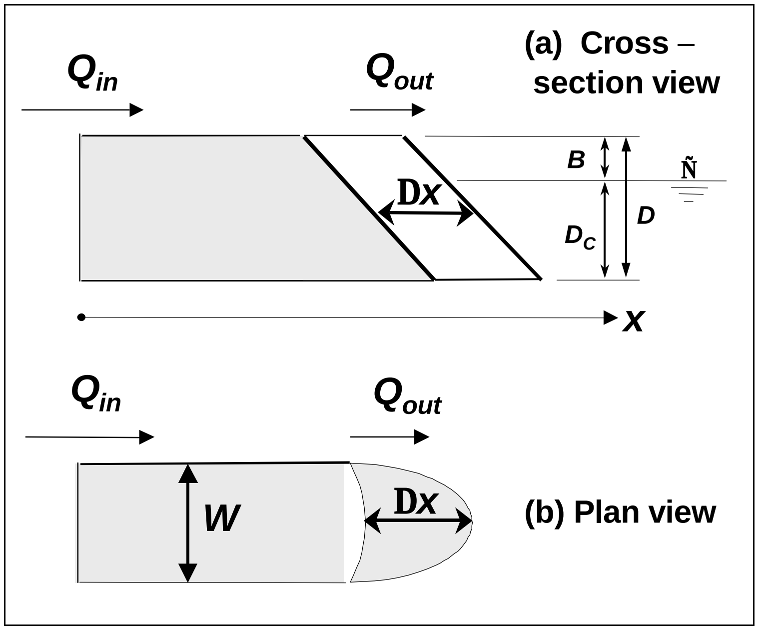

Fig. 1. Definition sketch for analytical model of spit elongation.

Viewing Fig. 1, in time interval Δt, the volume change ΔV equals $WD\Delta x$, for which the depth of active motion is $D = B + D_C$ (sum of the berm elevation and the depth of closure); and Δx is the increment of change in length of the spit in time Δt. By assumption, the volume change is equal to the volume entering minus that leaving during the time interval, i.e., $\Delta t(Q_{in} - Q_{out})$. In the limit, the sand conservation equation becomes

$$\frac{dx}{dt} = \frac{1}{WD}\left(Q_{in} - Q_{out}\right) \tag{1}$$

Solutions of the Eq. (1) are determined after specifying an initial condition, boundary condition and functional forms for the transport rates and other parameters, as appropriate. We now consider four examples of increasing complexity.

Example 1: Unrestricted Spit Growth

If a spit can elongate without restriction over the period under consideration, then $Q_{out} = 0$ (no sediment leaves or enters the spit from the distal end). Consider

$$Q_{in} = \overline{Q} + \frac{Q'}{2}\cos(\sigma t) \tag{2}$$

where $\overline{Q}$ = time-mean longshore sediment transport rate; $Q'/2$ = amplitude of a sinusoidal fluctuating rate; and σ = angular frequency of the motion, for example,

2π/year. Then, if the initial position of the spit at t = 0 is located at x = 0, the solution of Eq. 1 for the location of the tip of the spit, denoted as x_S, is

$$x_S = \frac{1}{WD}\left(\overline{Q}\,t + \frac{Q'}{2s}\sin(s\,t)\right) \tag{3}$$

Eq. 3 shows that spit elongation is directly proportional to the longshore sediment transport rate and to elapsed time, as modified by the fluctuating rate, and inversely proportional to spit width and depth of active movement. It is feasible that the spit could shorten during a transport reversal, depending on the magnitudes of $\overline{Q}$, Q', and σ.

The elongation rate of the time-dependent term in Eq. 3 depends inversely on the angular frequency. This means that, for the same amplitude of transport $Q'/2$, a higher-frequency motion will damp more quickly and be less-perceptible than a lower-frequency motion. As an example, suppose $Q_{in} = \overline{Q}$ = 100,000 m^3/year, D = 5 m, and W = 100 m. In addition, suppose that two sinusoidal forcings occur with respective angular frequencies of 2π/(1 year) and 2π/(1 month) and equal amplitude $Q'/2 = 50{,}000$ m^3/year. Then, in one year, x_S = 200 m, which is a plausible distance. Fig. 2 shows the linear growth of the spit as produced by the mean transport rate and the growth as modified by the two terms. The response of the spit to the monthly change in transport rate is barely perceptible despite having the same amplitude as the annual fluctuation.

For reference in interpreting the mean longshore transport rate, it can be shown that for N equi-spaced measurements of the rate, the net longshore transport rate $Q_n = N\overline{Q}$. For the remainder of this section, we take Q' = 0.

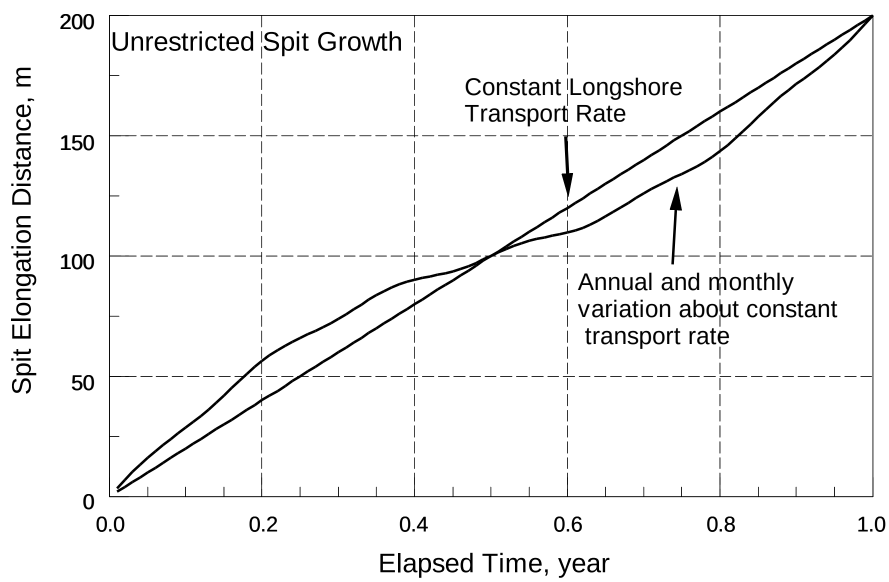

Fig. 2. Unrestricted spit elongation, constant and with time variation in transport.

Example 2: Spit Growth Restricted by Presence of Inlet Channel

As an inlet spit elongates, eventually its motion will be modified by the presence of the inlet channel or of an obstacle. Encroachment of the spit to a channel will tend to push the channel in the direction of spit migration, forcing the channel to migrate as in the case of Democrat Point and Fire Island Inlet, as described in the Introduction. On the other hand, the tidal current will tend to transport material off the tip of the spit, slowing its growth as compared to that given in Eq. 3 for unrestricted growth. At an inlet without stabilization structures, the competing processes of channel infilling by longshore transport and of channel scour by tidal and river discharge maintain a dynamic balance and equilibrium channel cross-sectional area. This balance has been examined quantitatively by Kraus (1998).

A phenomenological means of representing the scouring action of the channel in retarding spit growth is through an appropriate boundary condition for the transport rate Q_{out}. As one simple model of the boundary conditions, at a point x_o located far up-drift of the channel, the transport is unrestricted, so Q_{out} = 0. At the location of the channel (or another impediment to longshore transport), x_C, the spit will not elongate further if $Q_{out} = Q_{in}$. One simple representation of Q_{out} between x_o and x_C is to take a linear increase with distance moved toward the channel, as

$$Q_{out} = \left(\frac{x - x_o}{x_C - x_o}\right) Q_{in} \tag{4}$$

which satisfies the boundary conditions as stated. The situation is shown in Fig. 3.

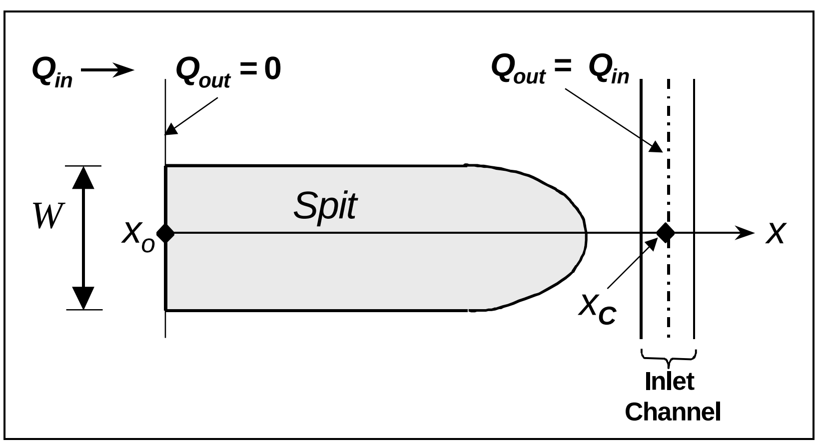

Fig. 3. Definition sketch for spit approaching an inlet channel.

The solution of the governing equation (Eq. 1) for this situation of restricted elongation with $Q_{in} = \hat{Q}$ (constant transport rate) is

$$x_S = x_o e^{-t/\tau} + x_C \left(1 - e^{-t/\tau}\right) \tag{5}$$

where τ is a characteristic relaxation time for spit elongation given by

$$t = \frac{WD\left(x_C - x_o\right)}{\hat{Q}} \tag{6}$$

For the numbers in the previous example, and with a lateral extension of 100 m, we have τ = (100 m x 5 m x 100 m)/(100,000 m^3/year) = 0.5 year. This appears to be a reasonable time scale for representing the motion of an organized sediment body. For this value of τ, and with x_o = 0 without loss of generality, Eq. 5 is plotted in Fig. 4 as the line labeled "Constant depth" for constant depth of active movement. As seen in Eq. 5, the rate of spit growth decreases exponentially as the spit approaches the channel.

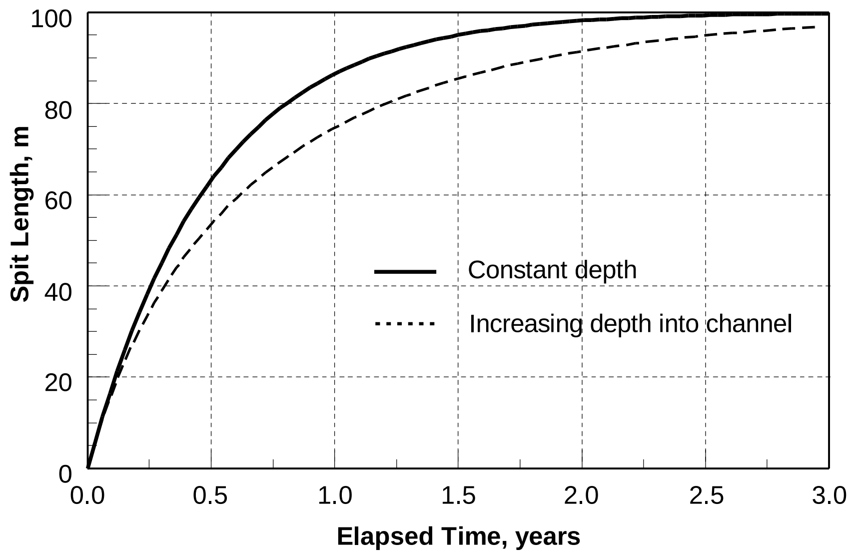

Fig. 4. Prediction of spit elongation by analytical model.

Example 3: Spit Growth Restricted by Inlet Channel and with Increasing *D*

This situation is the same as in the previous example, but is made more realistic by accounting for the depth of the channel. That is, the depth of active movement is assumed to increase with approach of the spit to the channel, i.e., the inlet channel thalweg is deeper than the ambient nearshore contours. For simplicity in obtaining an analytical solution, the depth is taken to increase linearly with fixed slope from some depth D_o distant from the channel (at x_o). So,

$$D = D_o + Sx \tag{7}$$

where $S = dD/dx$ = slope into the channel. The governing equation (Eq. 1), modified to include the x-dependence of D, becomes

$$\frac{dx}{dt} = \frac{1}{W\left(D_o + Sx\right)}\left(Q_{in} - Q_{out}\right) \tag{8}$$

It is seen that the presence of the slope term, making the depth of active movement increase, acts to slow the rate of growth with increasing distance. Applying the same condition on the Q's as in the previous example, Eq. 8 becomes

$$\frac{dx}{dt} = \frac{-\hat{Q}}{W(x_c - x_0)} \frac{x - x_c}{D_o - Sx} \tag{9}$$

The solution of this equation is

$$\ln\left(\frac{x - x_C}{x_o - x_C}\right) + \frac{S}{D_o - S x_C}(x - x_C) = -\frac{t}{\tau'} \tag{10}$$

where τ' is the characteristic time scale as modified by the channel slope, as

$$\tau' = \tau\left(1 + \frac{S}{D_o} x_C\right) \tag{11}$$

If $S = 0$, Eq. 10 reduces to Eq. 5. With S nonzero, Eq. 10 must be solved by iteration. A computer program was written for this purpose, and the result with the same values as in the previous example and for $S = 0.01$ is plotted in Fig. 4 with a dashed line. Because more material is required to elongate the spit as it approaches the (deeper) channel, a longer duration is necessary to extend the same length as for the case of constant depth of active movement.

Example 4: Spit Growth in Presence of Lateral Force

Wave-induced longshore currents and the direct impact of waves on the exposed end of a spit protruding into an inlet will tend to curve the distal portion of the spit away from the ocean. The flood current combined with wave-induced longshore currents and sediment transport around the distal end of a spit act together in curving the spit bayward. Focus of wave energy by refraction over an ebb-tidal shoal increases the trend of curving a spit.

Curving of a spit can be represented phenomenologically in a simple analytic-solution context by tracking a cross-shore component of movement of the tip of the spit. As an example, suppose the cross-shore (directed bayward) migration speed of the tip is a linear function of distance to the channel from some location far up drift of the inlet, as in previous examples. Then the cross-shore migration speed v_S of the tip of the spit can be represented as

$$v_S = \frac{x - x_o}{x_C - x_o} v_C \tag{12}$$

where v_C is the cross-shore migration speed of the spit at the center of the channel. The cross-shore coordinate of the spit tip y_S is given as

$$y_S = y_o + v_S t \tag{13}$$

where y_o is the cross-shore coordinate at the starting point of calculation located far up drift and may be taken to be zero in the present discussion. Fig. 5 plots motion of the tip spit, $x_S(t)$, $y_S(t)$ as for the previous example and with v_C = 5 m/year.

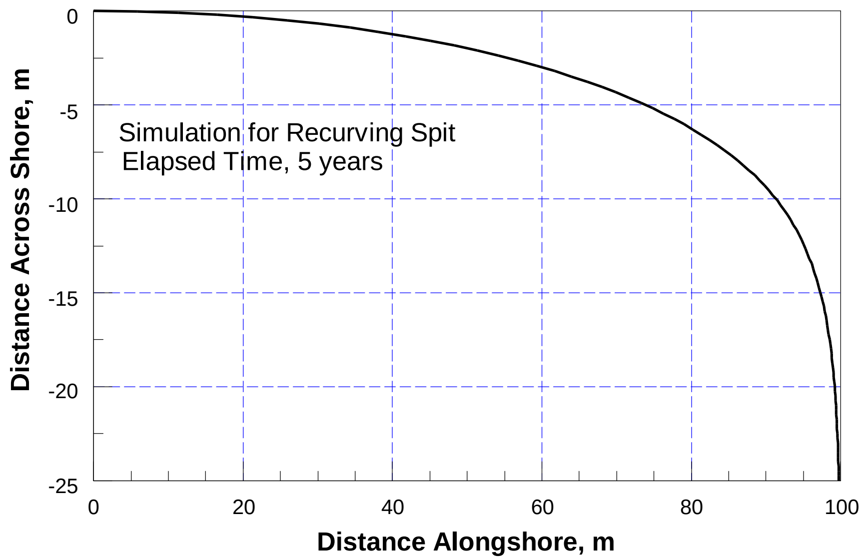

Fig. 5. Simulation of spit curving.

Discussion of Analytical Model Examples

The analytical model reveals the dependence of spit growth on fundamental geometric parameters, longshore sand transport rate, and time. A characteristic time constant τ is was obtained. Examples 2 and 3 demonstrate that the location of the tip of a spit at an inlet tends to be stable because material is swept from it by the channel current and because a channel tends to be deeper than the spit platform. Spit recurving was also reproduced in a simple way. The analytic approach is capable of yielding quantitative information, trends, and insight in through the compact form of simple equations. Generalization to complex dependencies is readily implemented numerically.

Trends of predictions are next examined through analysis of data from the field and from a physical model.

SPIT AT CORPUS CHRISTI BEACH

Corpus Christi Beach, traditionally called North Beach by the residents, is a bay shore, north-south trending beach located on the western side of Corpus Christi Bay, Texas (Fig. 6). The beach terminates at the north jetty of the Port of Corpus on its southern side and is now terminated by a groin 2.3 km to the north on its northern side. Corpus Christi Beach is a popular urban recreational area that began eroding notably after a series of hurricane landings in the early 1900s.

Starting about October 1977 and finishing in March 1978, the U.S. Army Corps of Engineers reconstructed the beach as a novel two-layer beach fill consisting of 382,000 m^3 of hydraulically-dredged silty sand covered by 300,000 m^3 of coarser

(0.4 mm median diameter) sand truck hauled from an inland source. The thickness of the sand cover ranged from 0.5 m on the berm and to 0.9 m on the foreshore. Kieslich and Brunt (1989) describe the beach fill, and Williams and Kraus (1999) review the hydrodynamics and meteorology of Corpus Christi Bay. To the author's knowledge, because of a policy change by the Federal Administration in the early 1980's, this fill may have been the last constructed by the Corps of Engineers with recreational benefits as a major justification.

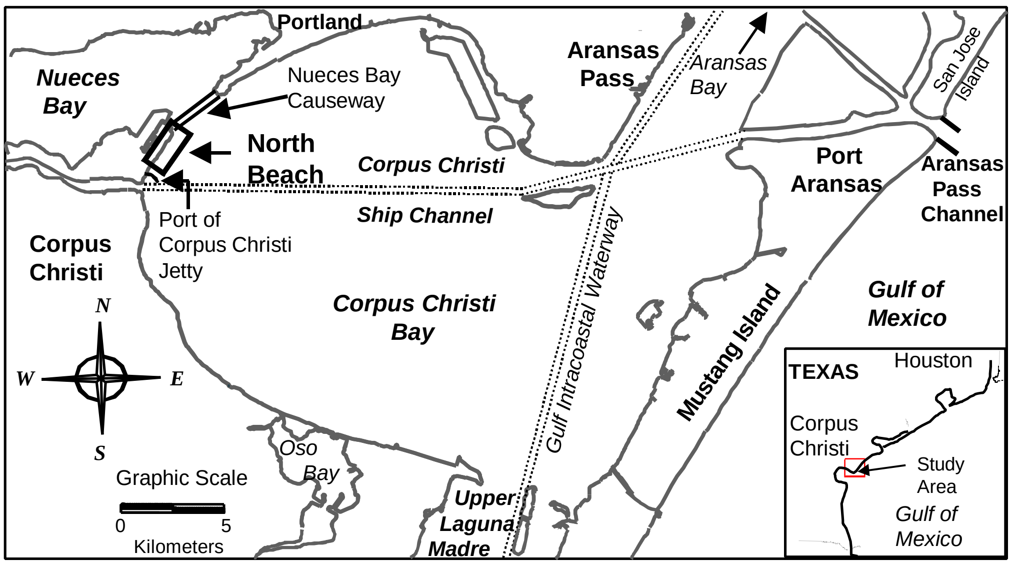

Fig. 6. Site location map for North Beach, Corpus Christi.

The beach fill was originally placed without a sand-retention structure on the northern end. As a result, the northern end of the beach experienced an average-annual loss of 9,200 m^3 for the 5-year post-construction period, about 70% of the total loss of the project (Kieslich and Brunt 1989). The loss on the northern end was predominantly by spit genesis and elongation northward toward Nueces Bay. Growth of the spit was documented annually or more frequently with vertical aerial photography, supplemented by oblique views. By 1982, the spit had extended more than 600 m to the north, where the Nueces Bay Causeway obstructed further lateral movement, and the spit began to widen where it impinged on the causeway.

The aerial photographs were digitized to document the position of the shoreline through time, yielding the location of the distal end and width of the spit. The photographs (of varying coverage) were scanned and rectified with at least three control points obtained from among 11 established by differential GPS with horizontal accuracy of ±0.30 cm (standard deviation). Tidal range on this end of Corpus Christi Bay is less than 20 cm from mean higher high water to mean lower low water. Median wave height for non-calm events is about 0.3 m, and mean period is about 3 sec. Therefore, because wave runup and the tidal range are small, the wet-dry boundary on aerial photographs can serve as a stable indicator of shoreline position.

The position of the distal end of the spit as determined from eight aerial photographs taken from 26 July 1977 to 7 December 1984 is plotted in Fig. 7, together with a linear regression line and 95% confidence limits. For the period plotted, it is evident that the North Beach spit grew in an unrestricted manner as described in the analytic model. The predominant direction of longshore transport is to the north, determined by predominant wind out of the southeast and by basin configuration, limiting the fetch to the north (Fig. 6).

Spit width from selected aerial photographs is plotted in Fig. 8. Beyond an elongation distance of about 500 m, the spit begins to spread as its platform reaches the causeway. The data exhibit scatter because of the occasional presence of washover fans. Although the astronomical tidal range in Corpus Christi Bay is small, weather fronts and hurricanes raise the water level and allow sand on the spit to be spread across shore by waves. For, example, in August 1980, Hurricane Allen inundated the spit for several hours (Kieslich and Brunt 1989). With time, spit width tends to increase gradually, as expected from the occurrence of small inundation events. As a short-term (several-year) value, spit width of W =20 m is taken to represent an assumed symmetric trapezoidal cross-section.

No profile data were available for the spit, but beach-fill-monitoring data are documented in Goldston Engineering, Inc. (1983), as in Fig. 9. The data show the berm elevation as about 0.9 m above MTL, and the bay bottom is flat at about 2.6 m, giving a total active depth of movement of 3.5 m.

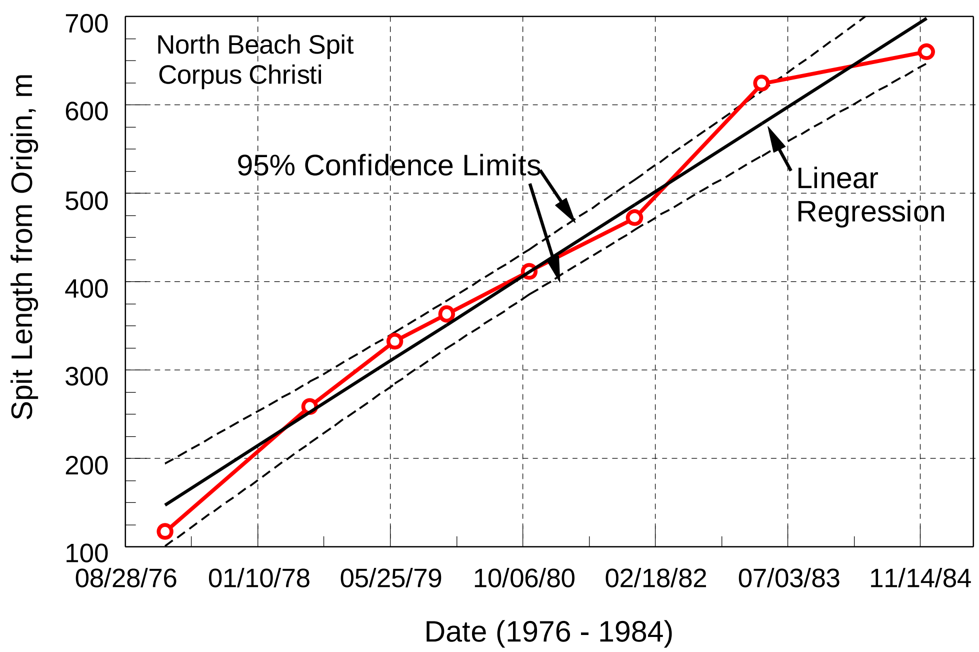

Fig. 7. Elongation of the spit at Corpus Christi (North) Beach.

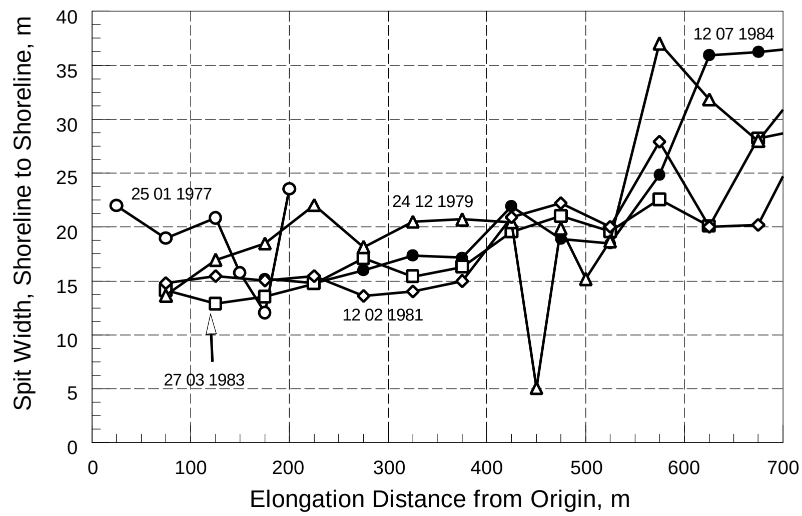

Fig. 8. Width of spit at Corpus Christi (North) Beach.

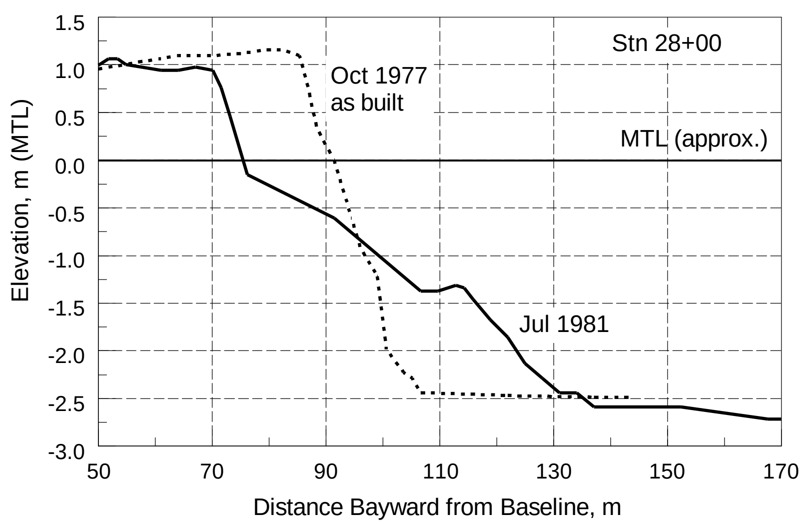

Fig. 9. Representative cross section of Corpus Christi (North) Beach.

Sufficient data are now assembled to test predictions of Eq. 2 of the analytical model for spit elongation. Fig. 7 indicates that application of a constant (average-annual) rate of longshore sediment transport is appropriate, and the equation becomes

$$\overline{Q} = \frac{WD}{t} x_S \approx \frac{20\ \mathrm{m} \times 3.5\ \mathrm{m}}{4.1\ \mathrm{year}} 500\ \mathrm{m} \approx 8{,}500\ \mathrm{m}^3 / \mathrm{year} \qquad (14)$$

This value is close to that (9,200 m^3/year) estimated by Kieslich and Brunt (1989) based on repetitive surveys made of the profile of the northern end of the beach fill. Rationally, it should be less than their value because some material observed to move from their profiles would have been transported to the south.

There is uncertainty in the analysis, in addition to model assumptions. As discussed by Kraus and Rosati (1999), uncertainty can be estimated by expanding all quantities in a Taylor series as, for example, as $\overline{Q} \rightarrow \overline{Q} \pm \delta\overline{Q}$, where the average rate on the left is interpreted as the actual rate and the right side is interpreted as a best estimate plus an uncertainty $\delta\overline{Q}$. Expanding the right side of Eq. 14 and keeping lowest-order terms, one obtains for an expression for the maximum uncertainty

$$\frac{\delta\overline{Q}}{\overline{Q}} = \pm\left(\frac{\delta W}{W} + \frac{\delta D}{D} + \frac{\delta x_S}{x_S} + \frac{\delta t}{t}\right) \tag{15}$$

which can be estimated from Eq. (15) as

$$\frac{\delta\overline{Q}}{\overline{Q}} = \pm\left(\frac{2}{20} + \frac{0.5}{3.5} + \frac{10}{500} + \frac{0.1}{4.1}\right) \approx \pm 29\% \tag{16}$$

If, instead, we can assume the individual uncertainties are independent and randomly distributed, then a root-mean square (rms) approach would give a more realistic value of the uncertainty as $\left(\delta\overline{Q}/Q\right)_{rms} = \pm 18\%$. The estimate of transport rates made by Kieslich and Brunt (1989) contains similar uncertainties, so both estimates, 9,200 and 8,500 m^3/year, are equivalent.

PHYSICAL MODEL STUDY

Spit evolution was examined in the Idealized Inlet Model installed at the U.S. Army Engineer Waterways Experiment Station (Seabergh 1999). This physical model supports basic and applied research through the Corps of Engineers' Coastal Inlets Research Program. The concrete basin (46 m wide, 99 m long, 0.6 m deep) contains an ocean and bay separated by a barrier spit bisected by an inlet. A movable wave generator located on the ocean side creates waves of fixed direction and variable height and period. Tidal variation can be specified, and storage tanks allow simulation of large back bays. Flows can be created and directed with piping and without changing the water level.

The present study was devised to examine dependencies of geometric parameters appearing in the analytical model and to observe integrated spit processes. For the study, 0.13-mm uniform quartz sand was placed along the updrift barrier islands as a 10-cm-thick veneer, and truncated approximately 2.1 m updrift of the entrance. Waves were applied at 20-deg angle (water depth at generator, 18 cm) to the shore to generate a longshore current and sand transport directed toward the inlet. With initiation of wave action, a spit emerged from the terminated movable bed and grew toward the inlet. The tests were performed in the presence of a curved ebb-tidal shoal, which tended to focus waves toward the inlet. Twenty-two cases were run with different wave height and period, fixed water level or with tide, and flow through the inlet as no flow, tidal flow, or a steady flood current. Wave height varied between 2.4 and 3.4 cm, and wave period between 1 and 2.2 sec.

Here selected properties of the new data set will be noted in relation to the analytical model. Trends are investigated without reference to scaling of field conditions. One concept explored analytically was that the elongation rate of a spit under constant longshore transport decreases with approach to a channel. Two possible reasons were implemented, one for which the depth of active movement increases, and the other was the sweeping action of the tidal current flowing through the inlet, which would remove material from the distal end of the spit.

Spit evolution in the physical model for two cases, plotted in Fig. 10, qualitatively displays the behavior calculated in the numerical mode (Fig. 4). Wave conditions were the same for both cases, with one being conducted with no tidal current and the other with a 17-cm/sec flood current, but no change in water elevation. Elongation of the spit follows a fairly smooth trend. Because the flood current enhances the wave-induced longshore current and increases the longshore transport rate, spit elongation is more rapid as compared to the case with only wave action. In the presence of the flood current, the tip of the spit reaches the channel (2.1-m distance) after about 80 min. Thereafter, the flood current swept material off the spit and it did not grow. In contrast, the spit created by wave action only had not yet arrived at the channel after 120 min.

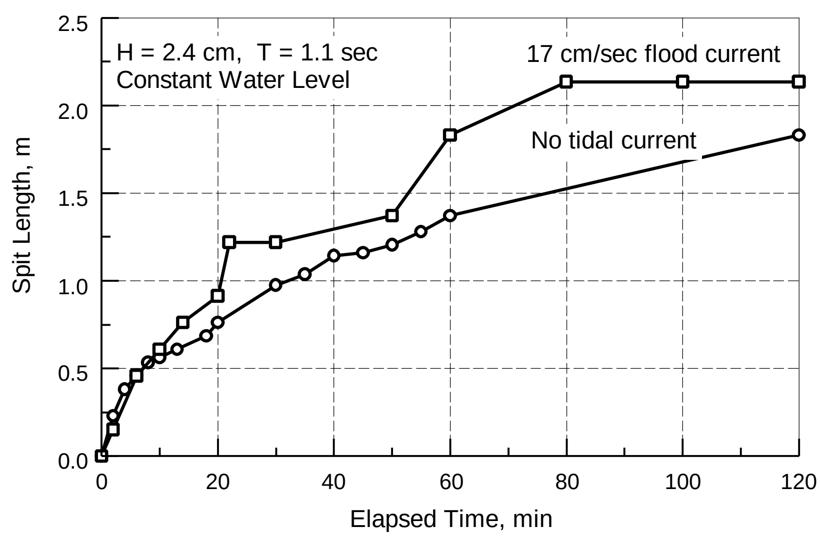

Fig. 10. Spit elongation with and without flood current, constant waves.

Spit width through time for the same case above with the flood current is plotted in Fig. 11. Each line in the figure shows width measured on cross-shore lines at 0.3048-m (1-ft) increments of distance alongshore downdrift from the spit genesis location on the barrier island. After 20 min, the spit had elongated slightly less than 1 m (Fig. 10); therefore, the first three cross-shore lines (at 0.30, 0.61, and 0.91 m) show non-zero width. As the spit reaches other downdrift lines, width can be measured on other lines in succession. Width of the spit at the more mature lines closest to the genesis point shows a trend for reaching equilibrium under the constant wave action. The lines at the distal end of the spit show a weaker but consistent trend. Although not shown here, a direct correlation was found in the physical model study whereby spit width increased with increasing wave period, increasing wave height, and increasing tidal range.

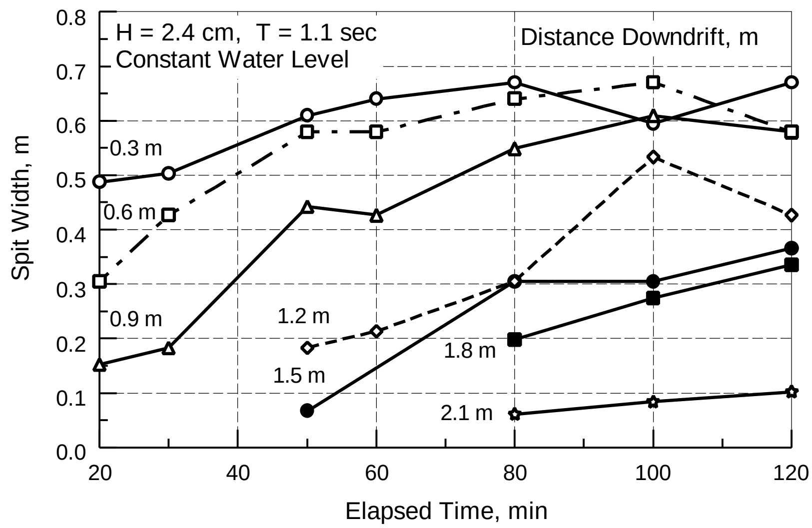

Fig. 11. Spit width in presence of flood current, constant waves.

CONCLUDING DISCUSSION

For an inlet spit or a spit created and maintained primarily by longshore sediment transport, it has been demonstrated that substantial progress can be made in quantifying spit evolution by analytic means. The approach, process-based modeling involving temporal and spatial scale (for example, hours to days and meters to hundreds of meters) appears capable of representing and predicting spit behavior for a wide range of hydrodynamic forces and ambient bathymetric conditions.

Parameters describing spit geometry and dynamics were classified according to relative time scale of the action of the governing physical processes. Through this classification, systematic study of spit dynamics can be made through field and laboratory measurement, as well as through analytical modeling. Movable-bed physical models have potential for providing considerable useful data to quantify spit dynamics in an integrated way under realistic conditions.

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